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EXPERIMENTAL INVESTIGATION OF FATIGUE PROPERTIES OF LAMINATED WOOD BEAMS

Lars Pilegaard Hansen *

The fatigue properties of wood and wood products have traditionally been ignored. Many structures of wood are subjected to static loads but some are also subjected to dynamic loads. It is therefore important to know the dynamic and fatigue properties of wood.
Many factors are determining the fatigue properties: the nature of the load acting on the structure, the load combinations, the type of wood, moisture content, temperature and so on.
This paper describes a series of tests made with laminated wood beams with different angles between the beam axis and the fibre direction for the laminates.

INTRODUCTION

Much more is known of the fatigue properties of metals especially steel and aluminium than is known of wood. Many structures of wood are primarily acted on by static forces and thus it is not necessary to know the dynamic and fatigue properties of wood. Some modern structures as large bridge structures in laminated wood and windmill blades made with different wood materials are examples of structures acted on by dynamic forces (traffic and wind). The possibility to make a more sophisticated analysis and design process with help of computers also call for more knowledge of the material properties of wood.

What is fatigue?

First of all it is necessary to define what fatigue is. Fatigue is here defined as the progressive damage and failure that occur when a structure or a part of a structure is subjected to repeated loads of a magnitude smaller than that corresponding to the static strength. Static strength means the traditionally strength measured at a normal static test of few minutes duration. The most used (and most simple) method to determine the fatigue properties of a given material or structure is to determine the so-called S-N-diagram by experiments. The S-N diagram is determined with the load varying harmonically within a given load range (or displacement range) and fixed frequency. The parameter S is for example the stress range for a simple tension experiment and N is the number of cycles to produce failure.

For a number of different specimens loaded to different maximum stresses several values of stress range and the number of cycles that produces failure can be determined. Normally N is plotted as the abscissa in logarithmic scale and S (the stress range) as ordinate

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(sometimes also in logarithmic scale). S is often normalized with respect to the static strength. As the magnitude of the stress range decreases the number of cycles to failure increases. Figure 1 shows examples of $S-N$–diagrams for mild steel, aluminium, concrete and wood. (Only in broad outline without details).

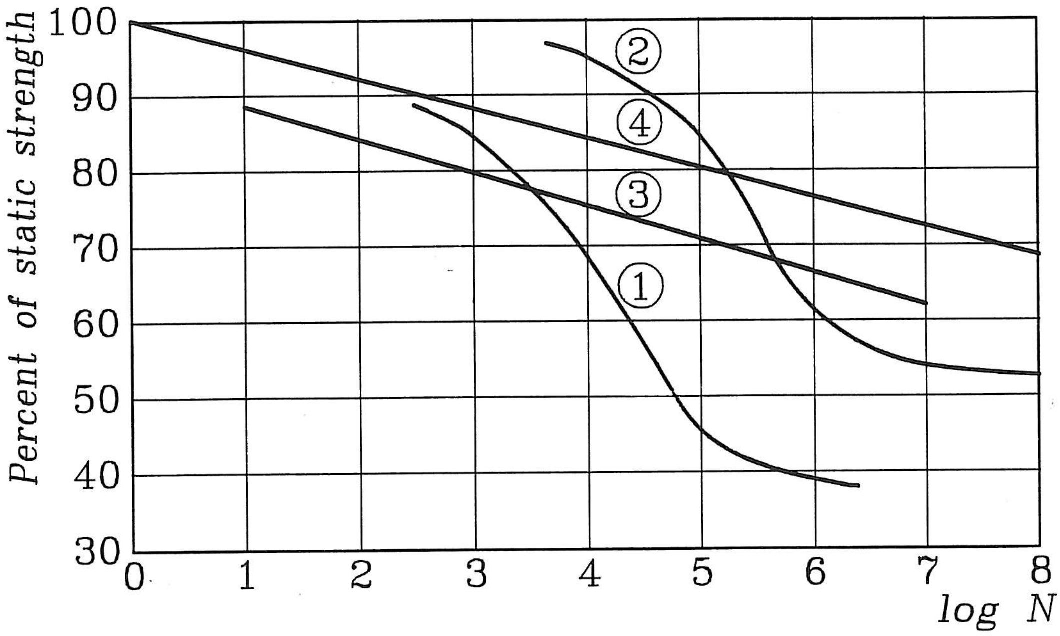


Figure 1. $S-N$–diagrams for 1 mild steel, see (1), 2 aluminium alloy 61S-T6, see (1), 3 concrete, see (2) and 4 wood, see figure 3, R=0.1.

FATIGUE PROPERTIES OF WOOD

Wood is an inhomogeneous and an anisotropic material, has a natural content of defects and exhibits time-dependent behaviour. Thus it is very difficult to describe wood especially with respect to such time-dependent properties as fatigue properties.

Some experiments have been made and some of the basic results from these experiments are summarized in the following. Further details are given in the references.

The fatigue properties of wood and wood products (for example laminated wood) are influenced by the following factors:

1. The type of wood for example softwood or hardwood, place of origin, density and the structural arrangement of the cellular level.

2. The size and shape of the test specimen. As for many other materials wood has a size effect giving greater strength for small specimens than for great specimens.

3. The moisture content has a significant influence on the characteristics of wood including the fatigue properties. An example is shown in figure 2 which shows that increasing moisture content results in a decrease in fatigue strength.

4. The type of load. Normally experiments are made as tests in tension, compression, bending or shear or a combination. Also multi-directional loading can be used. The loading conditions are very important and must be specified.

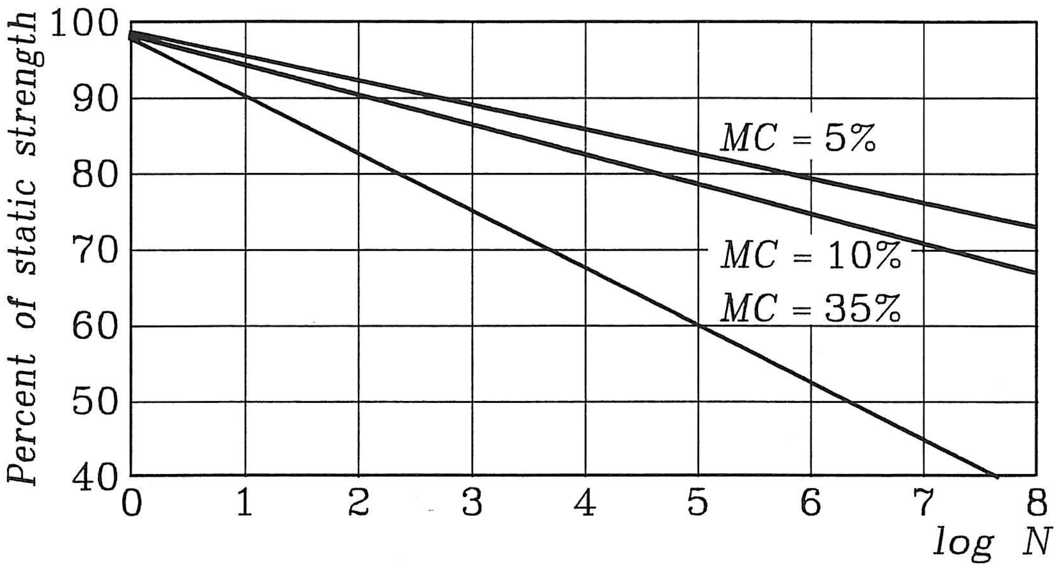


Figure 2. Influence of moisture content (MC) on fatigue strength of Khaya ivorensis laminates in four point flexure and R=0.1 as reported by Ansell in (3).

Most fatigue experiments are made with <u>harmonic loading</u> and for this type of loading 3 factors are of importance:

* The R-ratio defined as the ratio between the minimum stress (strain) and the maximum stress (strain). Negative values of R corresponds to so-called "reversed loading" and positive values of R to "repeated loading". An example of the influence of the R-ratio is given in figure 3.

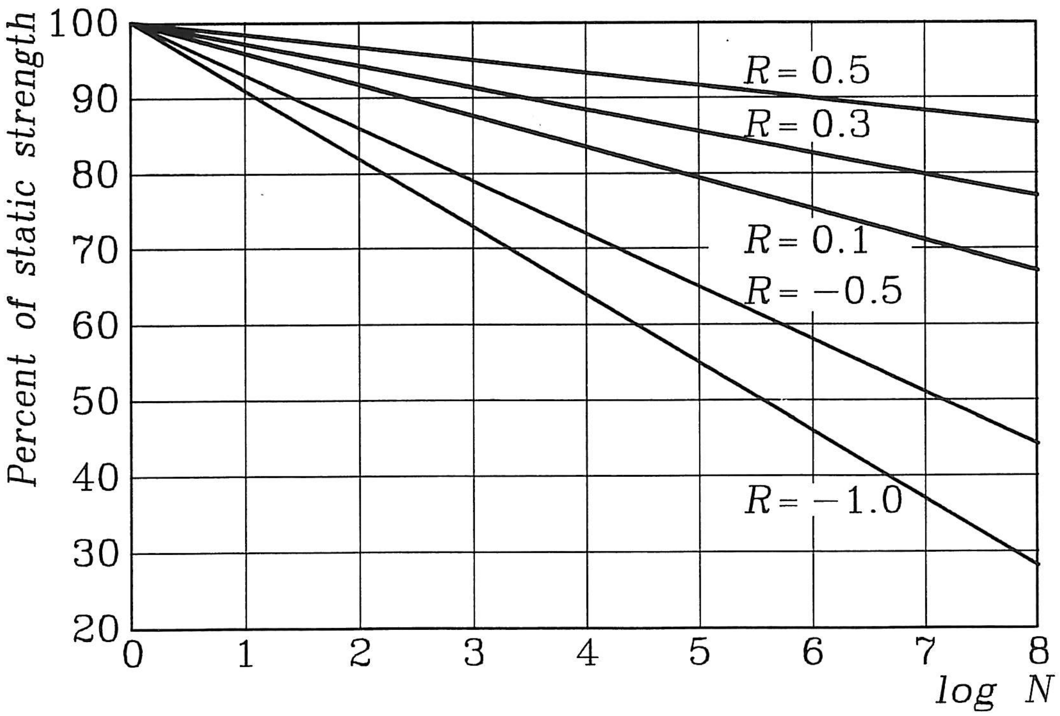


Figure 3. Influence of R-ratio on the fatigue properties of Khaya ivorensis laminates in four-point flexure and MC=10%. After Ansell, (3).

It is seen that the R-ratio has an important influence on the fatigue properties.

* The average value of the stress (strain). To the author's knowledge the influence of this parameter is not known in detail.

* The frequency and therefore also the total loading time from beginning to failure is also very important. As mentioned earlier wood is a material with time dependent properties and therefore loading time must be taken into account. Some $S-N$-diagrams for wood in compression are given in figure 4, and it is seen that especially for very low frequencies (corresponding to long loading time) there is a great influence of the frequency.

  It should also be mentioned that testing at high frequencies rises the temperature leading to moisture loss. Very high test frequencies should therefore be avoided.

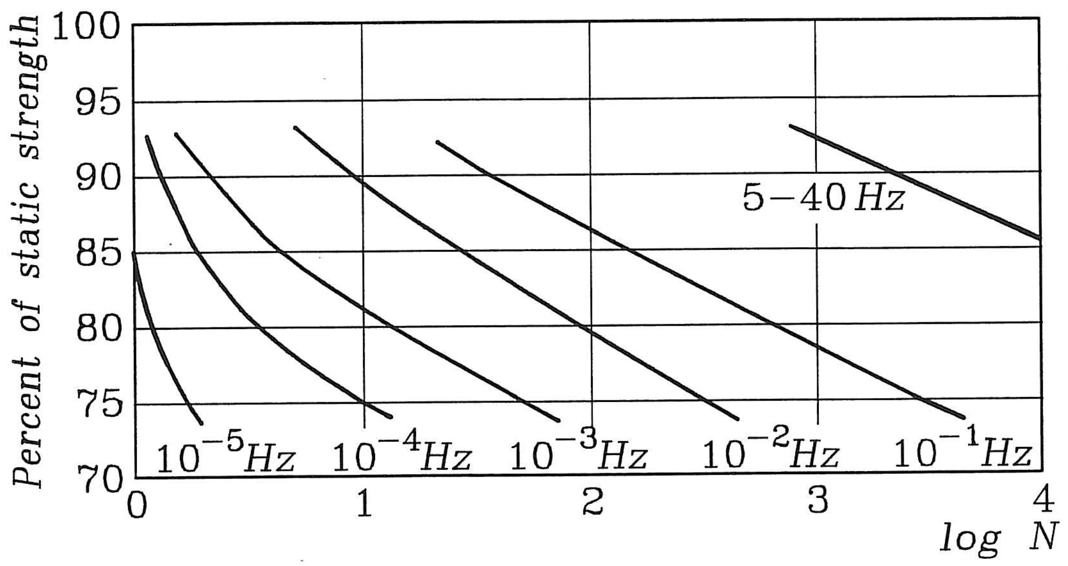


Figure 4. $S-N$-diagrams for wood in compression for different frequencies. After Bach (4).

The harmonic load situation is a theoretical one. The dynamic loads on most building structures are not harmonic but random in nature as for example wind, waves, traffic and earthquake loading. These types of loads are much more complicated to treat and to the author's knowledge only a very few fatigue experiments have been carried out with wood acted on by random loads.

5. Other factors effecting the fatigue properties of wood could be temperature, chemical treatments, gluing, fireproofing etc. In the next section of this paper another situation is treated:

   The influence of an angle between the direction of the fibres for the laminates and the beam axis for four-point flexure of laminated wood beams. This is for example of interest when the cross section of the beam varies and the sections are twisted in proportion to each other.

In (5) it is stated that wood behaves like a Damaged Viscoelastic Material and a so-called DVM-theory is developed. It is shown that the agreement between theoretical results and experimental data is very satisfactory.

For metals such as steel and aluminium fracture mechanics for some time has been used as a basic element for describing the fatigue process especially crack growth. Wood-related fracture mechanics research is as mentioned in (6) approaching the point where fracture-based failure criteria can be incorporated into practical design guidelines.

EXPERIMENTAL INVESTIGATION

At the Department of Building Technology, University of Aalborg, Denmark, some test series of laminated wood beams have been carried out. Some results from these tests are reported here.

Test arrangement and test beams

A photo of the test arrangement is shown in figure 5.

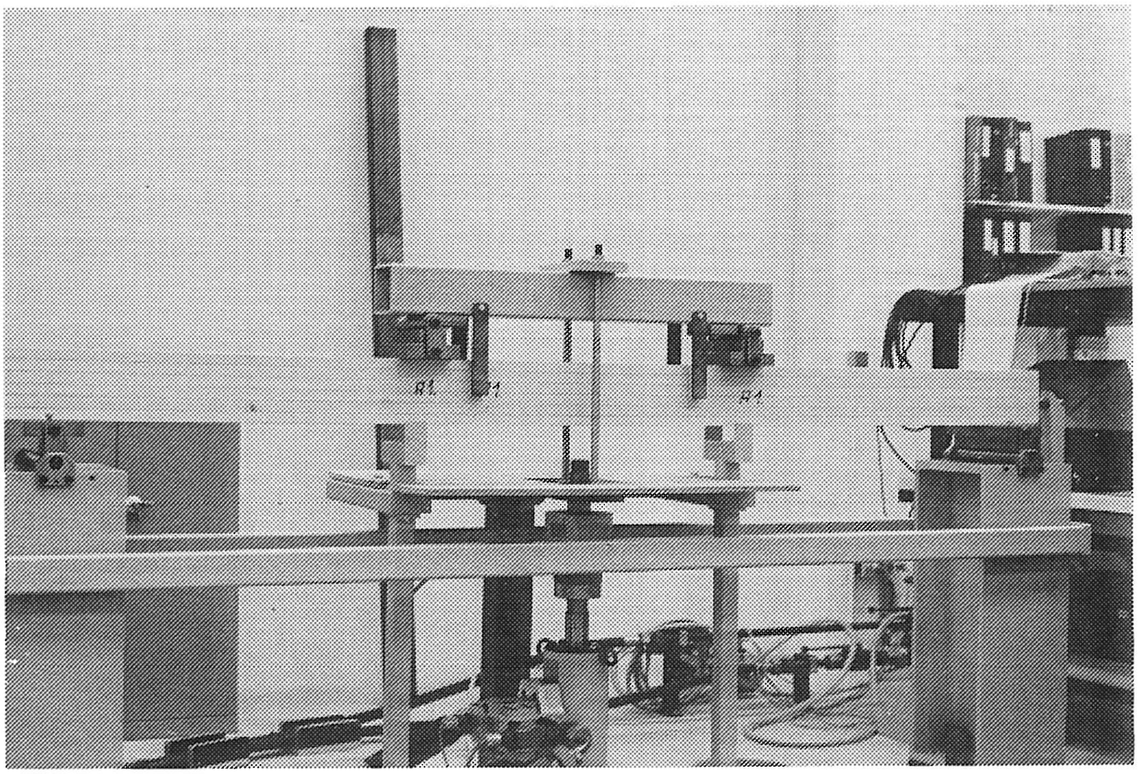


Figure 5. Test arrangement and test beam.

The test rig is designed for four point bending of simply supported laminated wood beams. The actuator is a 63 kN Schenck actuator connected to a Schenck servo-hydraulic testing system. The distance between the end supports is 2 m and the load from the actuator acts in the 1/3 points. These tests were all carried out as harmonically constant amplitude displacement - tests driven at a frequency of 10 Hz. Only one-sided loading was applied (so-called repeated loading) which means that there always is tension in the lower half part of the beam and compression in the upper half part. Constant amplitude displacement test means that the force from the actuator will decrease as the fatigue process proceeds. The cross section of the laminated beams is $w \times h = 60 \times 120$ mm consisting of 6 layers. The wood material was nordic spruce and the moisture content was approx. 12%.

The minimum value of the deflection was chosen to 3 mm and the maximum displacement varied for the different tests.

During the test the constant displacement range was controlled by measuring the displacement every 2 minutes as well as the force range. This was done with a HBM data aquisition system UHM 100 combined with a HP 9826 computer.

The test was stopped at break down of the beam or when the minimum value of the force reached a chosen limit (approx. 1 kN) or when approx. 2 million cycles were reached.

Before the fatigue test was started a usual load-deflection curve was determined and if possible the same was done after the fatigue process.

In this paper only the results from tests series A, B, C and D are stated.

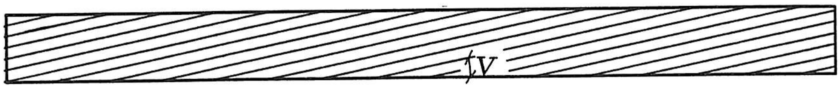
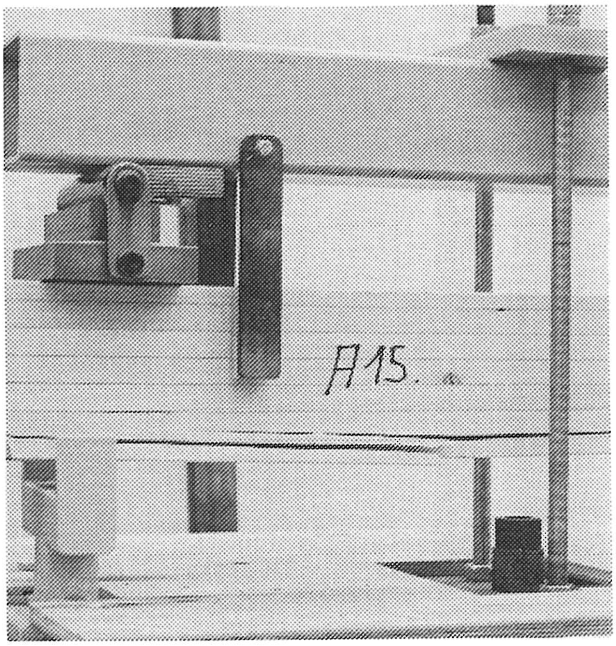


Figure 6. Angle v for test beams.

Figure 6 shows a sketch of a test beam. The angle v has different size namely: Series A: 0 deg. - Series B: 3 deg. - Series C: 6 deg. and Series D: 12 deg.

Test results

The most common types of fatigue ruptures were a compression rupture near the force attack point in the upper part of the beam or a tension rupture in the middle lower part of the beam. A typical tension rupture is seen in figure 7 for a beam in series A. The constant displacement range is 19 mm (min. = 3 mm and max.= 22 mm). Figure 7 also shows the load-deflection curve before and after the test. There is a remarkable decrease in stiffness.



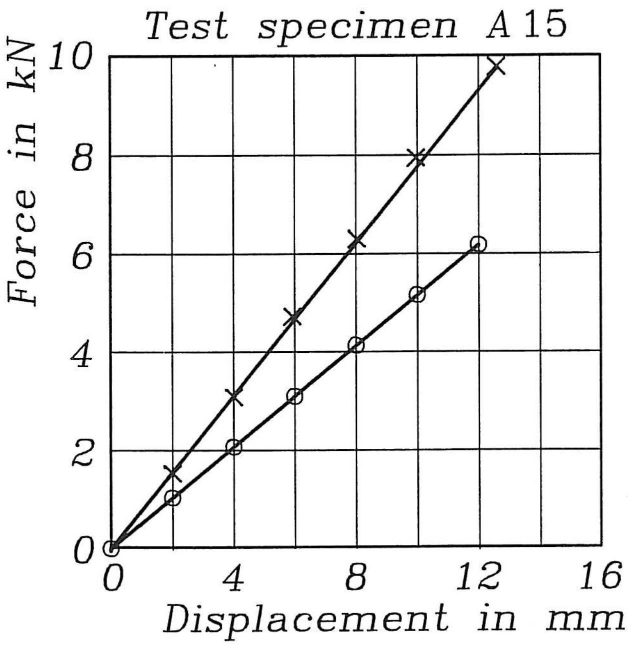


Figure 7. Photo of beam after fatigue test and load - deflection curve before (x) and after (o) test.

The variation of the maximum and minimum force during the test is shown in figure 8. It is seen that there is a sudden decrease in the maximum force for approx. 15000 cycles.

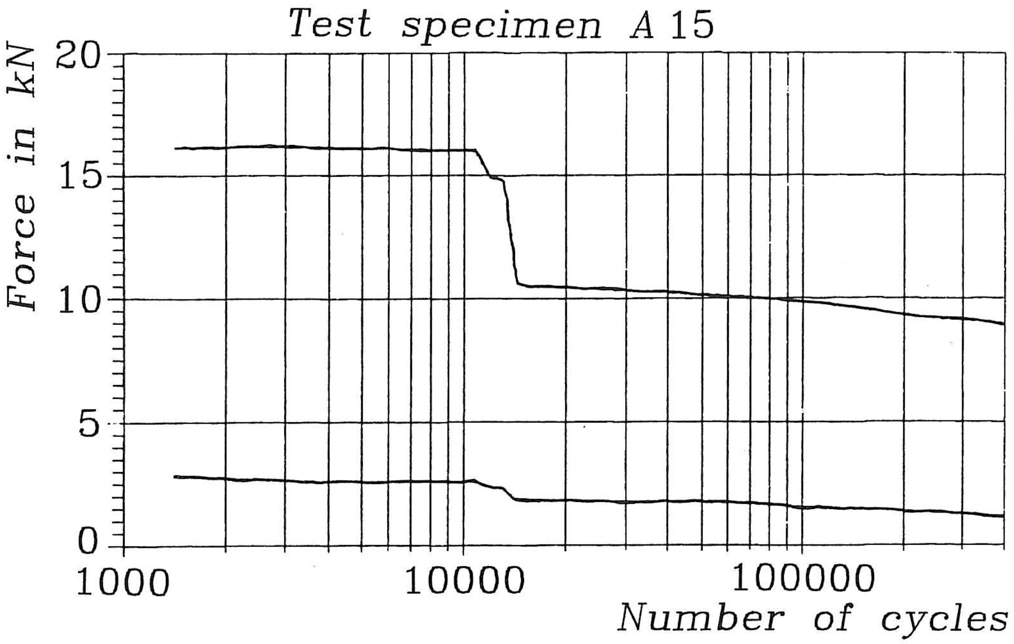


Figure 8. Variation of maximum and minimum force during test.

Figure 9 shows a $S-N$–diagram for the four series A, B, C and D. It is seen that there is a remarkable decrease in fatigue properties as the angle v between the fibre direction for the laminates and the beams axis increases. Some straight regression lines are drawn.

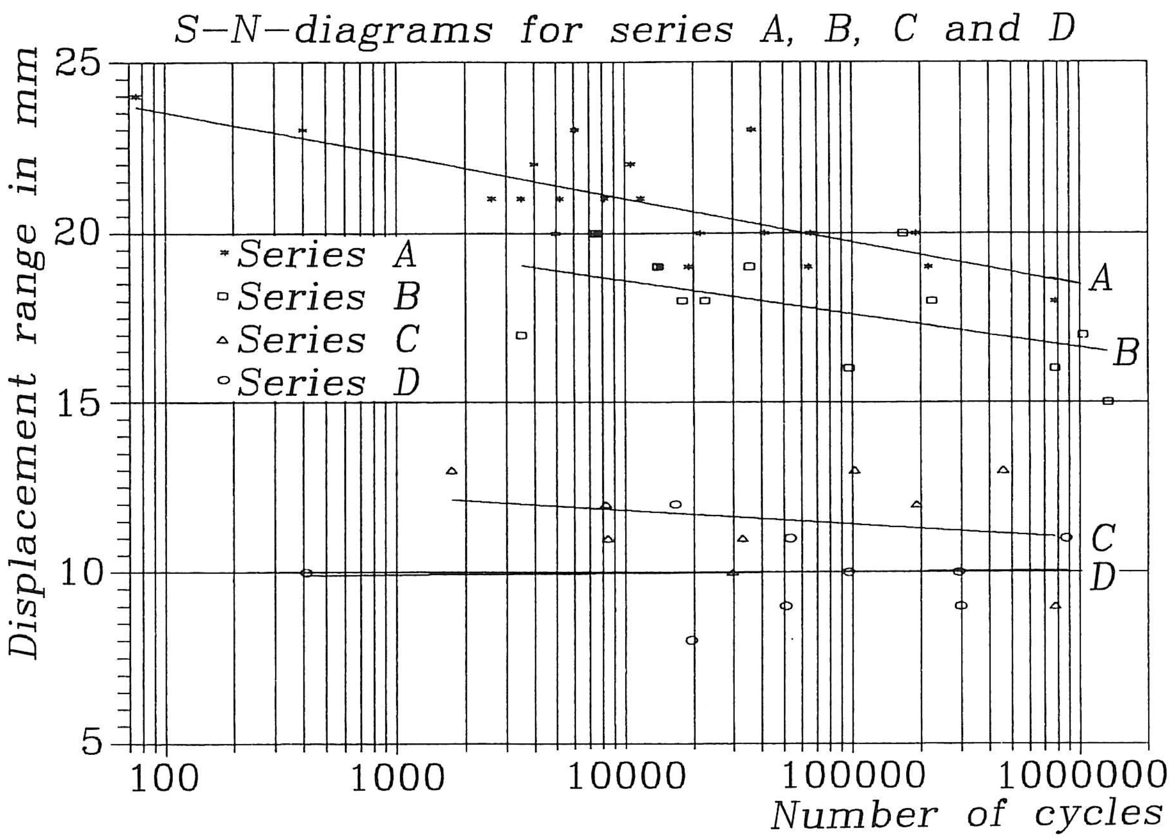


Figure 9. $S-N$–diagram for laminated wood beams in series A, B, C and D.

FURTHER RESEARCH

In addition to the above-mentioned tests for which the numerical work and presentation of results are not yet finished some other tests series have been carried out.

Analogous to the series A, B, C and D four other series E, F, G and H have been carried out. The only difference is that these series have a 5 mm reinforcement of wood with v=0 deg. glued to the lower side of the beam. This construction gives a remarkable increase of the fatigue properties.

The test arrangement has been redesigned. Both tension and compression forces can be transmitted to the wood beam. Moreover also a constant amplitude force test can be carried out. In such tests the displacement range will increase when the fatigue process goes on and when an upper limit is reached the test will be stopped if not broken.

These tests are planned in cooperation with the Building Materials Laboratory at The Technical University in Copenhagen, Denmark and are supported by a grant from The Danish Technical Research Council and The National Agency of Industry and Trade, Denmark.

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